

# Role of Pheromones and Kairmones for Insect Suppression Systems and Their Possible Health and Environmental Impacts

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Insects produce pheromones as a chemical communication system to facilitate reproduction. These highly active chemical attractants have been synthesized for some of the most important insect pests, including the boll weevil, gypsy moth, codling moth, tobacco budworm, European corn borer, and several bark beetles. While none of the synthetic sex attractants have yet been developed for use in insect control, they offer opportunities for the future both as control agents and to greatly improved insect detection. Investigations are underway on insect trapping systems employing the pheromones and on air permeation techniques to disrupt insect reproduction. The pheromones are generally highly species-specific and are not likely to pose hazards to nontarget organisms in the environment. Toxicological studies indicate that they are low in toxicity to mammals, birds, and fish, but adequate toxicological data are necessary before they can be registered for use in insect control. Another new class of compounds called kaironomes has been discovered. These chemicals are involved in the detection of hosts or prey by insect parasites and predators. Kairomones may prove useful in manipulating natural or released biological agents for more effective biological control of insect pests. No information is yet available on the toxicology of these chemicals.

One of the outstanding advances in recent years in the area of insect pest management has been the new developments in research on insect behavioral chemicals. These include the sex pheromones, a chemical communication system to assure successful reproduction, and the chemicals called kairomones that are involved in the detection of hosts or prey by insect parasite and insect predators. Chemicals called mating inhibitors or anti-pheromones that inhibit mate finding in insect have also been discovered that are of interest as insect control chemicals. These behavioral chemicals, which may involve a complex of compounds in some species, possess unusually high biological activity and are generally highly pest specific in action. Their availability to researchers has opened up new opportunities for the development of more

successful and desirable insect suppression and management systems.

It is a credit to the scientists in the chemical disciplines who developed chemical technology to the degree that has made it possible to isolate, identify, and synthesize the natural chemicals. They must work with minute amounts of the chemicals produced by the insects. The progress that has been made would not have been possible without the overall advances in chemical technology made during the past decade.

It is not yet clear how important these new behavioral chemicals will be in advancing insect suppression methods. However, there is every reason to believe that they will eventually play prominent roles, both directly and indirectly, in providing better solutions to a number of insect pest problems. They will also provide opportunities to gain more basic information on the ecology and behavior of insects in the natural environment.

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This could prove useful in developing more effective systems of insect control employing the weapons we already have.

There is an urgent need for more effective and more acceptable methods of control for many insect pests affecting agriculture and forestry, as well as those affecting the health of man and animals. We are still largely dependent on chemical insecticides to deal with insects that are important in limiting the production of food, fiber, and other essential agricultural products and which create health problems. The development of insecticide-resistant insects and the restrictions and bans on the use of some of our most effective insecticides have added to the urgency of finding new and more acceptable solutions to insect problems.

It must be emphasized, however, that the availability of the new behavioral chemicals does not mean that they can be used immediately to control a wide range of pests. Difficult problems in research and development must first be resolved before we will have a clear idea as to if and how they can be used to manage specific pests. This responsibility will fall largely on the biologists dealing with a diversity of insect species that vary in biology, behavior, and dynamics, and which differ in their relationship to the environment.

Much of the information on the biology, ecology, and behavior of insects that is relevant to effective and practical use of pheromones and kairomones is not essential in making effective use of chemical insecticides applied directly to plants, animals, or products. In contrast, however, the effective use of insect sex pheromones may require detailed information on the dynamics and reproductive behavior of the target pests in the natural environment. Major changes in concepts of the best way to cope with highly mobile insects that are capable of flying a hundred miles or more and which are capable of increasing from a low density to damaging numbers in a few generations, may have to be recognized, developed, and applied if we are to take maximum advantage of some of these new behavioral chemicals.

Notwithstanding our lack of knowledge at the present time, and the difficult and costly research needed, the prospects seem excellent for eventually making use of pheromones, antipheromones, kairomones, and perhaps other behavioral chemicals to improve insect suppression and management systems.

The use of such behavioral chemicals will entail problems of possible health and environmental impacts, not only due to the behavioral chemicals but perhaps even more importantly due to the

materials and devices that will have to be employed to make them useful.

## Available Pheromones and Kairomones

There is no intent to name all of the insect pheromones that have come into being in recent years. Moreover, research is underway on many other insects and the isolation, identification, and synthesis of new pheromones and antipheromones are reported at a rapid rate. However, the synthetic replicas of the natural attractants are already available for many of the Nation's more important insect pests. They include: cabbage looper, *Trichoplusia ni* (Hubner), (1); boll weevil, *Anthonomus grandis* Boheman (2,3); gypsy moth, *Porthetria dispar* (Linnaeus), (4); pink bollworm, *Pectinophora gossypiella* (Saunders), (5); tobacco budworm, *Heliothis virescens* (Fabricius), (6); European corn borer, *Ostrinia numitalis* (Hubner), (7); codling moth, *Laspeyresia pomonella* (L.), (8, 9); several species of bark beetles attacking forest trees (10-13); Douglas-fir tussock moth, *Hemerocampa pseudotsugata* McDonnough (formerly called *Ogyia pseudotsugata*), (14); and house fly, *Musca domestica* (L.), (15).

The insects named and others not listed for which pheromones have already been identified and synthesized cause perhaps more than a billion dollars' damage each year and are the target species for about half the insecticides used for agricultural purposes each year. Most of the pests are not adequately controlled by natural biological agents. Thus, the pheromones already known, if they can be employed for practical control, could contribute materially to a reduction in insect losses and also greatly alleviate environmental problems due to insecticides.

It would be unrealistic to infer, however, that insect pheromones will provide solutions to most insect problems and that they will obviate the need for chemical insecticides. Conventional insecticides will be required for most pests for the indefinite future. Indeed, even if powerful synthetic pheromones are available, the use of insecticides may be necessary for some pests to suppress populations to levels that will make pheromones practical for control. Thus, the two systems of pest control may be highly complementary in the solution of certain major pest problems.

The class of behavioral chemicals called kairomones already mentioned have just recently

come into being. The first compounds in this class were investigated by Lewis et al. (16) and identified and synthesized by Jones et al. (17-18). Specialists in the field of biological control are just beginning intensive investigations with synthetic kairomones to determine their role in parasite-host relationships. In my opinion, the discovery of the existence of these behavioral chemicals and the influence they have on parasite-host and predator-prey relationships represents one of the most important basic developments in the field of biological control of insects.

Natural biological agents constitute one of the great natural resources. Without them many insects now of no consequence would become pests and those that are pests would become of even greater importance. In all probability it would be impossible to cope with many insect problems by any method without the help of natural biological agents. At the same time, natural biological control agents developing on their own fall short of achieving effective control of many species, as evidenced by the fact that the various insects named and others have been major pests for years in spite of the presence of a diversity of natural control agents and before the intensive use of broad-spectrum chemicals disrupted the ecological balance of destructive and beneficial insects in some of our crop ecosystems. There are limits to the impact that natural control agents can have on host populations because of parasite-host density relationships.

To make use of natural control agents beyond that which can occur in a natural balance, we may have to employ artificial means to manipulate the number of certain agents for major pests. The use of kairomones may be vital to a high degree of success in this effort.

## How Pheromones Might Be Used to Advance Insect Suppression Systems

Synthetic insect sex pheromones are so new as a class of behavioral chemicals that the most effective and practical ways to employ them for insect control have not yet been determined. The manner in which these chemicals will be used will of course determine the nature of the health and environmental hazards that will be involved.

Research is underway primarily on two methods of using sex pheromones for insect control: the use of lures to attract the responding insects to their

destruction and the use of pheromones to prevent mating by confusing the sexes in their search for mates.

## Hazards Possibly Associated With the Trapping Technique

The most obvious method of employing attractants is to use a trapping device to capture, snare, or kill the insects responding to the attractant. If females only, or both sexes respond and are destroyed, control is achieved directly. For most pheromones, however, males only respond so that inhibition of reproduction can be achieved only by preventing the fertilization of females. It has been demonstrated in prior research on powerful male lures that effective control of insects can be achieved by male annihilation. This was demonstrated by Steiner (19), and Steiner and Lee (20), using methyl eugenol to annihilate males of the oriental fruit fly, *Dacus dorsalis* Hendel. Thus, the principle of insect control by preventing successful mating by males has been established. Since many of the insect sex pheromones are likely to be as powerful, if not more so than methyl eugenol for the attraction of males, there is reason to hope that sex pheromones can play a prominent role in insect suppression systems.

The trapping method is under investigation for most of the pheromones of the insects named as well as others. Encouraging results have been reported by the use of this technique for a number of species including the gypsy moth (21), the boll weevil (22-24); leafroller, *Argyrotaenia velutinana* (Walker), (25-27) western pine beetle, *Dendroctonus brevicornis* LeConte, (28); elm bark beetle (29).

Various techniques are employed in utilizing the trapping system. This will influence the nature of the hazards that might be involved. Traps may be designed to merely capture the insects so that they can not escape. It seems probable that no health hazards will be involved in the use of such technique. A large number of traps, if not removed from the trapping area, could lead to littering, which would be objectionable from an environmental standpoint. Most trapping techniques currently under investigation involve the use of resinous materials to snare the responding insects. Such materials are not likely to pose significant health or environmental hazards.

For some insects the only or most effective way to destroy the responding insects will be to apply a toxicant to the traps or apply a toxicant in the vicinity of the pheromone source so as to cause

death of the responding insects. Insecticides are used to destroy oriental fruit flies attracted to methyl eugenol. The use of insecticides as the killing agent could pose health and environmental problems of a toxicological nature that will have to be considered apart from the toxicity of the pheromone per se.

Consideration has also been given to the use of pheromones to concentrate the target pest into limited portions of the environment where they are then killed by the application of insecticides. This system of trapping has been employed experimentally against the boll weevil and may make possible the control of a high proportion of a boll weevil population on a given farm or ecosystem by treating perhaps not more than 5–10% of the acreage normally treated with insecticides. Thus, while such technique would still necessitate the use of conventional insecticides, it could reduce both the size of the area and the amount of insecticides required for controlling the pest.

### **Inhibition of Mating by Permeating the Air With Pheromone Vapors**

The confusion method involving the permeation of air in the insect habitat as proposed by Beroza (30) is also under investigation for most of the insects named. Investigations have included both pheromone attractants and inhibitors. Encouraging results have been reported for the gypsy moth (21, 31, 32); cabbage looper (33); pink bollworm (34); Douglas fir beetle, *Dendroctonus pseudotsugae* Hopkins, (35); and redbanded leafroller (26). Mitchell (36) has also reported encouraging results in the use of mating inhibitors. Various types of mating inhibitors may be combined to inhibit mating by several species in the same habitat.

Permeation of the air of the insect habitat with synthetic pheromones overpowers the amount of the natural pheromone produced by the insects and thus interferes with mate finding by the aggressor sex. Pheromone inhibitors may either mask the natural pheromone or cause a physiological disruption of the normal processes for detecting the mate. In any event, mating is inhibited. However, some insects possess supplementary mate detection mechanisms other than pheromone signals. Therefore, a high degree of inhibition of mating by the confusion technique may not occur under conditions of high pest density. The chances for mate finding by vision, sounds, or other supplementary detection methods are increased under high pest density conditions.

Various methods of disseminating the pheromones or mating inhibitors into the air may be involved. The pheromone may be released by natural volatilization or released as an aerosol by spraying devices. The pheromone may be encapsulated and the amount that permeates the air will be governed by the rate of release from the capsules. For most insects it will be necessary to maintain an effective concentration in the insect habitat over a period of several weeks or even months. In the case of the gypsy moth, 4–8 g/acre is likely to be required during the approximately 6-week mating season. Many nontarget as well as the target pests will be exposed to pheromone vapors in any treated area.

Knipling and McGuire (37) postulated that the efficiency of sex pheromone traps will depend on the relative attractant power of the pheromone in traps and the attractant power of the competing females or males within competitive range of the traps.

The theory that the efficiency of the trapping system is pest-density dependent has been confirmed in field tests with several insect species. Therefore, not only the strength and number of traps but their spatial relationship to the competing insects will be an important factor in efficiency. In all probability, therefore, the effective use of traps will require that considerable numbers of low cost traps will have to be employed in the pest environment even when the density of the pest is relatively low. The number of insects present during the lowest density in a seasonal or periodic cycle of the pest may be still too high to make the use of traps alone practical for the control of a pest. Therefore, it may be essential first to reduce the pest population by some other means. Thus, we must consider integrated suppression systems involving the use of chemical, cultural, or biological methods to reduce pest populations to levels that can be effectively managed by the use of pheromone traps.

The effectiveness of the air permeation method is also likely to be influenced by the density of the target pest as suggested by Beroza and Knipling (38). This has been confirmed in principle by field experiments against the gypsy moth (31). Therefore, the integration of other suppression methods may also be a requirement for the effective use of the air permeation method.

The influence of the pest density on the efficiency of mating inhibitors or antipheromones is not known. If these inhibitors mask the ability of the aggressor insect to detect pheromone signals and do not interfere with other mate-detection mechanisms, such as sight, their efficiency is also likely to

be dependent on pest density. On the other hand, if they prevent mating responses by interfering with physiological processes, their efficiency may be independent of the pest density. In such event, the same degree of mating inhibition can be expected by a given concentration of the inhibitor regardless of the target pest density. This would be highly advantageous in coping with high densities of a pest.

In view of the many unknowns at this stage in the investigations on pheromones, it is difficult to anticipate the type of health or environmental hazards that may be involved in their use. Every insect species will no doubt require a rather specialized application technique. However, pheromone vapors in the insect environment will be involved whether the pheromones are used in the trapping or confusion techniques. Therefore, it will be necessary to determine the effect of pheromone vapors on other organisms in the target pest environment. If the pheromones are applied to the environment in small capsules or other particulate matter, they could also be ingested by nontarget organisms, such as fish and wildlife. However, we are dealing with substances that exist naturally in environments. Nontarget animals are exposed to vapors of pheromones that are produced naturally. Fish, birds, and other predators consume insects and ingest the natural pheromones. Therefore, the nontarget organisms are also exposed to the natural products.

## Use of Pheromones for Insect Detection

While the importance of insect sex pheromones as a direct means of insect control is not yet clearly apparent, they will unquestionably play a prominent role in insect detection systems. Pheromones are already in use by Federal and State regulatory agencies for surveys and detection of the gypsy moth, pink bollworm, boll weevil, and other pests. Investigations are underway on pheromones of various other species in efforts to improve pest management systems by determining where and when control measures need to be applied.

The availability of these new and powerful attractants for early detection of insects in new areas of spread will in time add a new dimension to insect eradication and containment programs. Early detection of incipient populations of pests by the use of powerful chemical lures has been the key to keeping our mainland free of several species of tropical fruit flies (39, 40). Eradication measures for most of these very important pests of citrus and other tropical fruits are available. No doubt sex pheromones

can in the future play a similar role in preventing the establishment of other pests that may spread to new areas.

The use of pheromones for insect detection in support of regulatory programs and population assessment in support of insect management programs will in all probability involve the use of traps of some kind. The number of traps required for such purposes will certainly be fewer than will be required for suppression. Thus, the hazards associated with the use of pheromones for survey purposes should be minimal as compared with their use in suppression systems.

It might be added, however, that how to relate the pheromone trap capture data to pest management actions will require additional research and experience with most pheromones. The rate of capture in light traps or traps baited with ordinary chemical attractants is likely to be proportional to the density of the pest population. However, because of the competition of the pheromones produced by insects in the natural population with the pheromones in baited traps, the rate of capture in widely spaced survey traps may be a poor indication of the pest density, particularly when the pest densities are moderate to high and relatively few widely spaced survey traps are employed.

## Use of Kairomones to Enhance Control by Biological Agents

The manner in which kairomones will be used for insect control is even less clear than for pheromones. However, these chemicals, if used for manipulating the action of natural or released biological control agents, will no doubt involve the direct application of the chemicals to crops where the natural agents and the insect hosts occur. They might also be applied to parasites or predators to stimulate host seeking when released in augmentation systems. W. J. Lewis and his associates of the U.S. Department of Agriculture, Tifton, Georgia (personal communications), have found that very small amounts of the synthetic kairomones are required to stimulate host seeking by *Trichogramma evanescens* (Westwood). Less than 1 g/acre of tricosene applied to foliage of crops increased host seeking by the *Trichogramma* parasites.

No definite information is yet available on the toxicity of tricosene and 13-methylhentriacontane, two chemicals known to stimulate host seeking by parasites. However, the small amounts necessary and the chemical nature of the compounds indicate that their use is not likely to pose significant health hazards; nevertheless as with pheromones, it will be

necessary to obtain toxicological data on these chemicals before they can be used.

A problem of possible ecological significance may be involved in the use of kairomones that needs to be considered and perhaps investigated. This would be the possible impact of widespread use of kairomones on the natural balance of biological organisms and their hosts in the total ecosystem. It is conceivable that the use of kairomones in restricted areas or on a given crop will cause a concentration of biological agents in the treated areas and reduce the number of such agents in the surrounding untreated areas. Accordingly, the degree of natural control in the untreated areas may be affected.

The above indicate the kinds of environmental problems likely to be associated with the use of kairomones, but the availability of these behavioral chemicals should offer new opportunities for gaining more help from natural or augmented parasites and predators in the management of insect pests, which could alleviate the amount of insecticides required for their control.

## Toxicology of Insect Sex Pheromones

In efforts to obtain toxicological data on insect sex pheromones I communicated with a number of investigators working on different pheromones. Through the cooperation of several investigators it was possible to obtain both published and unpublished data summarized in this report.

Information on the toxicology of insect sex pheromones is limited. Most of the information is summarized in Table 1. Available data on disparlure, looplure, and muscalure were taken from a

publication by Beroze et al. (41), except for the subacute toxicity data for disparlure in the diet of quail chicks, which were furnished by R. L. Cowden of the Animal and Plant Health Inspection Services, U.S. Department of Agriculture. Cowden also furnished data on the toxicity of grandlure to quail chicks. The data on the exo-brevicomin, frontalin, and myrecene composition for the western pine beetle were supplied by William D. Bedard, U.S. Forest Service. In addition, Engler of the Environmental Protection Agency provided data on the acute toxicity of codlamone to rats and rabbits and data on the effects of muscalure on reproduction of mallard ducks and bobwhite quail. Codlamone has an LD<sub>50</sub> in excess of 3250 mg/kg when fed to rats for 5 days. It proved nonirritating when tested as a skin irritant and as an eye irritant on rabbits.

Although limited, the available acute and subacute toxicity data on five pheromones indicate that these chemicals possess a very low order of toxicity to animals and fish. To indicate the relative toxicity of the pheromones and other insecticidal chemicals it may be pointed out that in the subacute diet tests involving quail chicks, the 8-day LD<sub>50</sub> value for dieldrin tested currently was 31.8 ppm. Also, concurrent tests conducted with toxaphene against rainbow trout showed a 96-hr LD<sub>50</sub> value of about 0.02 ppm.

Results of eye irritation and skin irritation tests on rabbits with disparlure, looplure, and muscalure are also presented in the publication by Beroza et al. (41). Results of similar tests were provided by Bedard for the attractant of the western pine beetle. These tests indicate that the compounds are not considered eye or skin irritants as defined by the Federal Hazardous Substances Act.

Muscamone (muscalure) caused a reduction of reproductive success for mallard ducks receiving 2

Table 1. Toxicity of insect sex pheromones.

Pheromone	Insect species	Acute oral LD <sub>50</sub> (rats) mg/kg <sup>a</sup>	Acute dermal LD <sub>50</sub> (rabbits) mg/kg <sup>a</sup>	Subacute toxicity (bobwhite quail chicks), ppm in diet <sup>b</sup>	Inhalation no-effect level, mg/l. <sup>c</sup>	LD <sub>50</sub> (rainbow trout 96 hr), ppm <sup>d</sup>
Disparlure	Gypsy moth	> 34,600	> 2025	> 5000	> 5	> 100
Grandlure	Boll weevil	—	—	> 5000	—	—
Looplure	Cabbage looper	> 13,430	> 2025	—	> 4.5	> 100
Muscalure	House fly	> 23,070	> 2025	—	> 26.6	—
Exo-brevicomin:1	Western pine beetle	2,240	5110	—	120	—
Frontalin:1						
Myrecene:1						

<sup>a</sup>Four animals per test, except for the pheromone of the western pine beetle, which involved six animals at each dose tested.

<sup>b</sup>Ten quail chicks were exposed to the diet for 8 days.

<sup>c</sup>Ten rats per test, except six mice were exposed to the pheromone of the western pine beetle.

<sup>d</sup>Ten fish were exposed at each of four concentrations. No deaths occurred at maximum of 100 ppm.

and 20 ppm of muscamone in the diet for 22 weeks. No adverse effect on reproduction in bobwhite quail was evident using the same concentrations in the diet for 23 weeks. In general, available data indicate that the pheromones tested are of a low order of toxicity. Moreover, insect sex pheromones are likely to be used in small amounts in comparison with most insect-control chemicals. The synthetic pheromones are similar to or identical to the chemicals produced naturally by the pests to be surveyed or controlled. There is no evidence that natural pheromones create hazards to natural organisms in the same environment. Therefore, there is reason to be optimistic that the behavioral chemicals will pose no serious health or environmental hazards.

Notwithstanding the probability that the use of insect sex pheromones will create little or no hazard, the attractant chemicals are classed as pesticides under the Federal Insecticide, Fungicide and Rodenticide Act, as amended by the Federal Environmental Pesticide Control Act of 1972. Therefore, toxicological and environmental impact data are needed to register the behavioral chemical for use against the pest to be controlled. It seems important, therefore, that necessary toxicological and environmental hazardous studies be undertaken on all compounds that may prove useful for insect control. Protocols for undertaking the type of test necessary are being developed by the Environmental Protection Agency.

## Discussion of Research Needs

The availability of powerful and seemingly highly pest-selective behavioral chemicals opens new avenues of attack on insect pests that could in due time result in changes in concepts of the best strategies for coping with a number of pests, particularly certain major species that cause high losses each year and which are responsible for the use of most of the ecologically disruptive insecticides applied in agricultural environments.

The potential uses for insect sex pheromones and mating inhibitors may be summarized as follows: (1) for insect surveys and detection in support of pest management, pest containment, and pest eradication programs employing other suppression methods; (2) for use against established pests that normally reach low densities to prevent or delay the development of economic populations during a seasonal cycle; (3) to maintain subeconomic populations of established pests that are first reduced by other means to levels that can be effectively managed by the use of the

pheromones; (4) to prevent the establishment of pests in new areas of spread; (5) to eliminate isolated incipient populations in new areas of spread; (6) to eradicate established insect populations from isolated areas that have first been reduced by other methods of suppression.

Much research needs to be done to make use of insect sex pheromones for the purposes listed. The most urgent and perhaps the most difficult aspects of research will involve field evaluations. Many factors are likely to influence the effectiveness of pheromones in actual field use. The density of the target pest, the degree and extent of migration during different periods in a seasonal or periodic cycle of a pest and the mating behavior are some of the biological variables that are likely to be highly important. Also, physical factors such as temperature and air movement will influence results.

Since the density of the pest is likely to be a limiting factor in the efficiency of pheromones used in traps or when permeated into the air to inhibit mating, these chemicals may not be practical for use after pest populations have approached or reached the damage level. Accordingly, pheromones may have their greatest value in preventive entomology and particularly as one component in an integrated attack on pest populations. If the species are highly mobile, such programs may not be successful unless carried out in an organized way against total or large segments of a pest ecosystem. Thus, changes in concepts of the way to attack major pest problems and public support for such approach will be necessary. The indicated high degree of selective action of most pheromones against specific pests would justify every effort to develop them for use in total population management programs, so as to alleviate or minimize the need for other chemical control methods that are likely to pose greater health and environmental hazards.

Information on the toxicology of pheromones is still limited, but the data available on a number of pheromones indicate that they are of low order of toxicity. No evidence of adverse impacts on the environment have been reported in the field trials that have been conducted. However, much more research on the basic toxicity, both acute and chronic will be required, and observations under field conditions will be necessary to determine, case by case, if environmental hazards in their use will occur. Financial support for such research should receive a high priority. The Environmental Protection Agency needs to establish guidelines for determining the safety of pheromones. Such guidelines are under study but they are not yet available.

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